Journal of Contemporary Educational Research, 2025, Volume 9, Issue 12
http://ojs.bbwpublisher.com/index.php/JCER
ISSN Online: 2208-8474
ISSN Print: 2208-8466

Construction and Outcomes of a Higher Vocational Chemical Engineering Talent Cultivation Model Based on a Science-Education Integrated Course

Hualiang Zuo, Jun Wang, Jianhui Zhang, Jichang Li, Wenhua Zhao*

Zhongshan Polytechnic, Zhongshan 528400, Guangdong, China

**Author to whom correspondence should be addressed.*

Abstract: To address the new demands for highly skilled technical personnel arising from the upgrading of the chemical industry and to resolve the disconnect between traditional higher vocational education in chemistry/chemical engineering and corporate needs, this study utilized the Organic Chemistry course as a vehicle to construct and implement a teaching reform model centered on "Integration of Science and Education" (ISE). Guided by the objectives of "aligning with industry, empowering students, and enhancing employment competitiveness," the study systematically designed a three-dimensional linkage mechanism encompassing "resources, methods, and evaluation." This involved: constructing teaching resources aligned with authentic enterprise projects; innovating the PBL-IGT (Problem-chain Based Learning & Inquiry-Guided Training) teaching methodology that simulates R&D processes; and implementing a diversified assessment system incorporating enterprise evaluation perspectives, thereby comprehensively reshaping the course ecology. After two rounds of teaching practice, data indicate that students in the experimental class showed significant improvement in key development indicators, including job adaptability, technical thinking proficiency, and professional identity. This study confirms that the model effectively bridges the "last mile" from the classroom to the workplace, providing a validated pathway for cultivating innovative, multidisciplinary technical talents that meet the demands of modern chemical enterprises.

Keywords: Integration of science and education (ISE); Higher vocational education; Organic Chemistry; Job competency; PBL-IGT teaching methodology

Online publication: December 31, 2025

1. Introduction

Currently, China is undergoing a strategic transformation from a "large chemical country" to a "strong chemical power." The rise of strategic emerging industries such as new materials, new energy, and biomedicine has placed unprecedented demands on the knowledge structure, competency, and professional ethos of technical and skilled personnel in the chemical field [1]. Enterprises urgently need not merely “craftsmen” capable of performing repetitive operations, but “field engineers” and “technicians” who can understand process principles, optimize production flows, handle unexpected failures, and possess certain technological innovation capabilities. However, there remains a noticeable “mismatch between supply and demand” when comparing the output quality of talent cultivation in chemical engineering majors at higher vocational colleges in China with this pressing need.

This mismatch is particularly acute in foundational professional courses like Organic Chemistry [2]. As a bridge connecting basic theory and professional skills, the teaching quality of this course directly impacts students’ depth of understanding of subsequent professional courses and their potential for future career development. Yet, traditional teaching models commonly suffer from three major drawbacks [3]: Firstly, lagging teaching content. Textbook updates are slow, creating a generational gap between the knowledge points taught and the mainstream technologies and green chemistry concepts currently applied in industry, resulting in a mismatch between what students learn and what enterprises use. Secondly, singular teaching methods. The infusion-style teaching of “teacher lectures, students listen; teacher demonstrates, students imitate” suppresses students’ active thinking and inquiry spirit, failing to cultivate their ability to solve uncertain problems. Thirdly, biased evaluation orientation. The summative evaluation of “one exam determines all,” focusing on knowledge memorization and reproduction, cannot scientifically measure students’ development in deeper professional qualities such as practical ability, innovative thinking, and collaborative spirit. These drawbacks collectively lead to the awkward situation where graduates face “insufficient theoretical knowledge, weak hands-on ability, lack of innovative awareness, and long job adaptation cycles.”

2. Theoretical guidance and research positioning of science-education integration

As a key pathway to promote high-quality development in vocational education, the core connotation of “Science-Education Integration” lies in organically integrating the mindset, methods, and cutting-edge achievements of scientific research, as well as the latest developments in industrial technology, into the entire process of talent cultivation, thereby achieving a benign interaction between teaching and research and resonance between schools and industry. It requires vocational education to transcend the narrow vision of “skill training” and rise to the strategic height of “cultivating technological literacy and innovation capability” [4,5].

Although the importance of ISE has become a consensus, existing research and practice exhibit two obvious tendencies: First, a predominant focus on undergraduate and postgraduate education, exploring how to cultivate students’ academic innovation ability through research training; Second, relevant explorations in the higher vocational field often remain at the level of macro conceptual exposition or scattered attempts at teaching methods, lacking a complete, systematically designed, and empirically validated model from the holistic perspective of talent cultivation [6]. Specifically, three key questions have not been adequately addressed: First, how to transform “esoteric” research and “vivid” industrial technology into teaching carriers that higher vocational students can understand, find interesting, and operate? Second, how to design a teaching process that allows students to personally experience and undergo work processes similar to enterprise technical activities while mastering knowledge and skills, thereby internalizing professional roles and norms? Third, how to establish an evaluation mechanism that can not only accurately assess learning outcomes but also function as a “baton,” guiding students to grow towards the competency model desired by enterprises [7]?

This study precisely aims to confront the aforementioned challenges. Using the higher vocational Organic Chemistry course as a "testing ground," we aim to construct a curriculum reform model with "Science-Education Integration" as its soul and "enhancing core professional competitiveness" as its fundamental goal. Through rigorous evaluation of its practical effectiveness, we seek to answer the core research question: How can a systematic ISE mechanism effectively empower higher vocational students to grow into excellent technical talents better aligned with the needs of modern chemical enterprises?

3. Design of the ISE mechanism for professional competency development

Based on constructivist learning theory, situated learning theory, and the concept of deep industry-education integration, we constructed a closed-loop system model with "cultivating innovative technical talents meeting enterprise needs" as the fundamental goal, "Science-Education Integration" as the guiding thread, and encompassing three pillars: "teaching resource platform, teaching method innovation, and assessment & evaluation system" (**Figure 1**). The innovation of this model lies in the precise alignment and deep coupling of each component with authentic enterprise demands and professional competency standards.

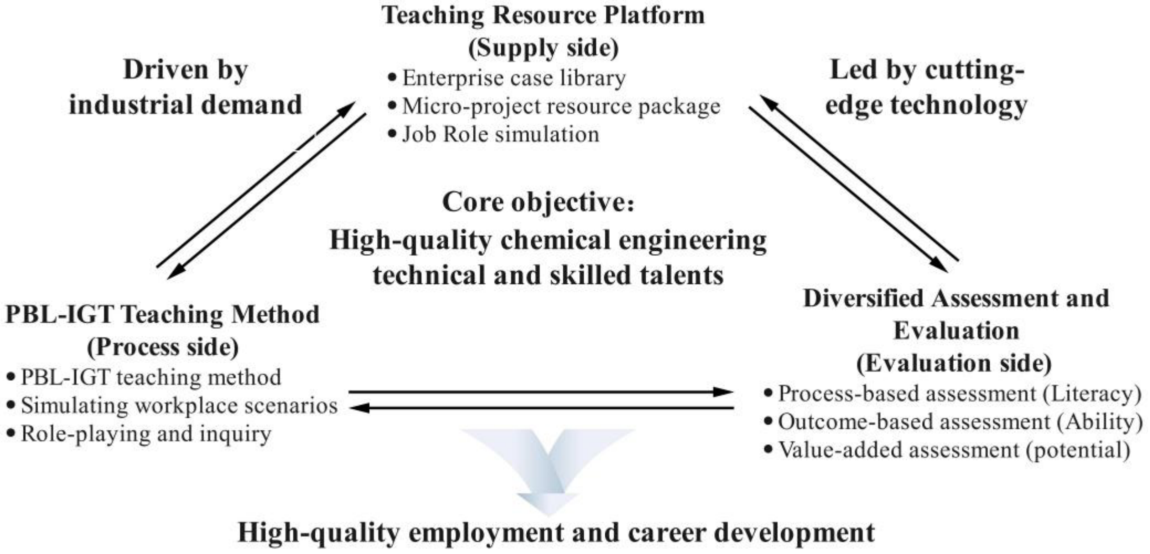

Figure 1. Three-dimensional linkage model for science-education integration targeting professional competency development

3.1. Resource platform: Building a "sourced from enterprises, applied to positions" teaching resource repository

The resource platform serves as the bridge connecting the classroom and the enterprise. We abandoned the "working behind closed doors" approach to resource development, instead constructing a resource system that resonates with enterprise technological activities.

3.1.1. Repository of transformed authentic enterprise cases

Developed jointly with cooperative chemical enterprises, this involves transforming typical technical problems from production (e.g., "product impurity analysis," "catalyst efficiency improvement," "optimization of waste treatment processes") into teaching cases. For instance, when teaching "esterification reaction," the case of "synthesis of Polyethylene Terephthalate (PET) from Terephthalic Acid (PTA) and Ethylene Glycol (EG)" is introduced. Terephthalic acid (a diacid) and ethylene glycol (a diol) undergo a series of reactions, including esterification and polycondensation, to ultimately produce PET resin. PET is the primary raw material for manufacturing beverage bottles and polyester textile fibers. This case effectively links the small-molecule "esterification reaction" with the polymer "polycondensation reaction," allowing students to see how simple chemical reactions from textbooks are industrially scaled up to become ubiquitous materials in daily life.

3.1.2. Micro-project resource packages for job skills

These packages simulate enterprise R&D or production tasks, such as "Synthesis and Performance Testing of Acrylic Resin for Waterborne Coatings" and "Synthesis and Blending of Specific Esters in Daily-use Fragrances." Each package not only includes a technical task description but also specifically adds "Job Role Descriptions" (e.g., R&D personnel, quality inspector, process technician) and "Industry Norms and Standards" (e.g., GMP, ISO9001), enabling students to perceive professional roles and establish awareness of standards and safety regulations during their studies.

3.2. Teaching method: Creating the "simulating workplace, immersive inquiry" PBL-IGT teaching methodology

To allow students to experience the complete workflow of enterprise technical work on campus, we integrated the essence of PBL (Problem-Based Learning) [8,9] and IGT (Inquiry-Guided Training) [10] to innovate the "Problem-chain Based Learning & Inquiry-Guided Training (PBL-IGT)" teaching methodology. Its core is simulating the project working mode of an enterprise R&D department.

3.2.1. Role-playing and situational immersion

At the beginning of the course, students are divided into several "project groups." Students in each group take turns playing roles such as "project leader," "lab technician," "data analyst," and "safety officer," endowing them with clear professional responsibilities.

3.2.2. Problem-chain simulating technical breakthroughs

The teacher, acting as the "technical supervisor," releases project tasks and decomposes complex tasks into "problem-chains," simulating the logical path of enterprise technical breakthroughs. For example, in the "Optimizing Aspirin Synthesis Process" project, the problem-chain is: "1. (Literature Review) What are the current mainstream process routes? What are their respective advantages and disadvantages? 2. (Mechanism Analysis) What are the key factors affecting yield and purity? 3. (Experimental Design) How to design experiments to verify and optimize these parameters? 4. (Economic Analysis) How to balance yield, cost, and environmental requirements?"

3.2.3. Collaborative inquiry and process standardization

Each project group operates in the laboratory, which serves as a "simulated workshop" or "R&D lab," strictly following enterprise-style standard operating procedures (SOPs) and safety management regulations, cultivating students' rigorous, standardized work style.

3.2.4. Outcome review and reflective debriefing

Upon project completion, each group presents their solution or product and defends it. The evaluation criteria focus not only on technical results but also on solution feasibility, cost awareness, teamwork, and the problem-solving process, guiding students through "work debriefing" to transform experience into learning.

3.3. Pillar three: Implementing a "competency-based, development-oriented" diversified assessment and evaluation system

Evaluation serves as the "weather vane" for talent cultivation. To break away from "score-only" evaluation and comprehensively and fairly assess students' professional competency and development potential, we constructed a "trinity" assessment system incorporating enterprise evaluation perspectives.

Formative assessment (40%): Focuses on the formation of professional behavior and literacy. Specifically includes: Quality of participation in classroom and group discussions (10%, assessing communication and expression skills); Operational standardization, safety awareness, and environmental habits during experiments/projects (15%, corresponding to enterprise 6S management requirements); Timeliness, authenticity, and completeness of lab records (10%, corresponding to enterprise technical documentation management requirements); Contribution level in roles played within team projects (5%, determined through peer assessment within the group and teacher observation).

Summative assessment (40%): Focuses on the quality of completing job tasks and awareness of technological innovation. Mainly includes: Micro-project research report (25%, evaluated from multiple dimensions: scientific rigor, standardization, innovativeness, feasibility); Final comprehensive practical skills examination (10%, simulating enterprise pre-job skills assessment); Design of an innovative solution for a specific practical problem (5%, encouraging creative ideas).

Value-added assessment (20%): Focuses on students' potential for professional growth and enhancement of soft skills. This is a distinctive and highlighted feature of our system. At the course's outset, we administered a pre-test to all students using a self-developed Higher Vocational Chemical Engineering Student Professional Competency Scale. This scale covers multiple dimensions, including "technical comprehension," "systemic thinking," "innovation confidence," "team leadership," and "professional identity." A post-test is conducted after the course. The student's value-added score is the standardized result of their degree of improvement from the post-test relative to the pre-test. This design fully embodies the "student-centered" educational philosophy. It acknowledges and respects individual student differences, focusing primarily on their "growth value" rather than "starting point value." This greatly motivates students at all levels, especially those with weaker foundations, allowing them to see their own room for progress and thus exert their full effort.

4. Educational outcomes: Data based on competency enhancement and employment competitiveness

To verify the effectiveness of the aforementioned mechanism, this study selected two parallel classes in chemical engineering-related majors at our institution for a comparative teaching experiment. The experimental class employed the new ISE model, while the control class used the traditional teaching model. Both classes were taught by the same instructor, used the same textbook, and ensured consistent teaching hours.

4.1. Comparative analysis of quantitative data

4.1.1. Survey on professional competency and literacy

After the course, we conducted an anonymous survey on Course Teaching and Professional Competency Cultivation Effectiveness Feedback among all students in both the experimental and control classes. Data shows that compared to the control class, the experimental class showed improvements of 36.5% in "job understanding and adaptability," 31.8% in "technical thinking and problem-solving ability," 44.7% in "professional identity and sense of responsibility," and additionally, 36.7% in "learning and innovation confidence."

4.1.2. Comparison of enterprise evaluations during internship

We tracked and analyzed the evaluation reports of participating students during their subsequent internship periods. Results show that the proportion of experimental class students receiving "excellent" internship evaluations was 45.3%, compared to 22.9% for the control class, a significant difference of 22.4% points in favor of the experimental class. Relevant enterprises noted that experimental class students had "solid foundations, quick getting started, followed rules, were good at communication, and possessed preliminary problem-analysis ability."

4.2. Analysis of student feedback

To understand the stories behind the data, we conducted in-depth interviews with students from the experimental class with different academic backgrounds. We extracted the following representative feedback:

Student A (excellent academic foundation): "Previous experiments were 'following a recipe.' Now it's completely project-based. Our group searched the literature ourselves, designed comparative experiments to optimize caffeine extraction yield, and held 'debriefing meetings' together to find reasons after failures. When we finally obtained caffeine crystals using our own optimized process, the sense of achievement was indescribable. I felt I was no longer just a student, but a real R&D personnel."

Student B (average academic foundation): "The value-added assessment lifted a burden off me. I know my theory isn't the strongest, but as long as I think actively in projects, operate carefully, and contribute to the team, my effort and progress are seen and recognized. This made me dare to voice my ideas in discussions, not afraid of making mistakes."

The above data and interview materials collectively indicate that the ISE mechanism designed in this study not only achieved significant improvement in professional competency and literacy, but more importantly, had a positive and profound impact on stimulating learning interest, cultivating innovative thinking, and practical ability in deeper dimensions.

5. Discussion: The internal logic and success factors of ISE empowering higher vocational talent cultivation

The success of this reform is not due to the improvement of a single process but is the inevitable result of the systematic linkage of "resources, methods, and evaluation." Its internal logic lies in accurately achieving deep "alignment" at three levels:

Alignment of teaching content with work content: Solves the problem of "what to learn." By transforming authentic enterprise projects and technical cases into teaching resources, we broke down the knowledge barrier between school and enterprise, keeping teaching content synchronized with industrial technological development, ensuring the "timeliness" and "practicality" of the knowledge students acquire.

Alignment of learning process with work process: Solves the problem of "how to learn." The PBL-IGT teaching method, by simulating the complete context and workflow of enterprise technical activities, allows students to complete a role rehearsal from "student" to "quasi-employee" on campus. This not only imparts skills but also deeply internalizes professional culture, including rigorous standardization, teamwork, cost awareness, and green concepts.

Alignment of academic evaluation with talent evaluation: Solves the problem of “how to evaluate.” The diversified evaluation system, particularly its focus on process literacy and growth potential, makes the course’s assessment standards highly convergent with enterprise standards for evaluating employees. This “baton” effectively guides students to consciously develop towards the competency model desired by enterprises, achieving the unity of “evaluation” and “cultivation.”

Furthermore, the introduction of “value-added evaluation” is a major innovation of this model. It reflects the essence of vocational education as “adult education,” i.e., focusing on the life growth of each individual. By affirming student progress, it protects and stimulates the broadest learning enthusiasm, paving a hopeful path towards professional success for all students, regardless of their starting point.

6. Conclusion and outlook

By systematically designing and practicing the “Science-Education Integration” mechanism in the higher vocational Organic Chemistry course, this study strongly demonstrates an effective pathway to enhance the quality of technical and skilled talent cultivation. Through systematic reform in three-dimensional linkage, this model deeply integrates industrial needs and scientific research thinking into the course’s lifeblood, successfully transforming course teaching from isolated, static knowledge transmission to the comprehensive forging of students’ professional competency, innovative literacy, and comprehensive development potential.

Its successful experience indicates that reform of higher vocational courses must break out of the mindset of single-point optimization and undertake top-level design and systematic reconstruction. Future work will focus on: First, deepening industry-education collaboration, promoting the institutionalization and regularization of mechanisms for co-establishing industry colleges with enterprises, co-compiling loose-leaf textbooks, and co-teaching courses. Second, enhancing the “dual-qualification” literacy of the teaching faculty, through establishing teacher enterprise workstations, joint technical R&D projects, etc., and continuously improving teachers’ own industrial experience and technological innovation capabilities. Third, constructing a big data tracking system for graduate career development, long-term tracking of graduates’ career advancement, salary levels, innovation performance, etc., using longer-term evidence to feed back into and optimize the talent cultivation program.

Acknowledgments

The authors thank the support from Zhongshan Polytechnic.

Funding

Higher Vocational Education Teaching Research and Reform Project of Guangdong Higher Education Teaching Management Society “Research and Practice on the Cultivation of Innovative Skilled Talents in Higher Vocational Colleges from the Perspective of Science-Education Integration” (GDGX202401036); High-level Talent Project of Zhongshan Polytechnic “Research on the Electrochemical Catalytic Oxidation of 5-Hydroxymethylfurfural to 2,5-Furandicarboxylic Acid Based on Bimetallic Catalysts” (KYG2301)

Disclosure statement

The authors declare no conflict of interest.

References

[1] Ministry of Industry and Information Technology, National Development and Reform Commission, Ministry of Science and Technology, Ministry of Ecology and Environment, Ministry of Emergency Management, National Energy Administration, 2022, Guiding Opinions on Promoting High-Quality Development of the Petrochemical and Chemical Industry During the “14th Five-Year Plan” Period.

[2] Bao X, Tian C, 2023, Reform of Teaching Methods for Organic Chemistry Course in Higher Vocational Education. Chemical Enterprise Management, (03): 22–25.

[3] Zhang W, 2020, Teaching Model Reform in Higher Vocational Colleges: Innovative Practice Based on Extreme Learning Process. Chinese Vocational and Technical Education, (08): 60–66.

[4] Jiang W, Zhou L, 2025, The Value Implication, Realistic Dilemmas, and Practical Pathways of Science-Education Integration in Vocational Education under the Background of Building a Strong Education Nation. Chinese Vocational and Technical Education, (18): 72–80.

[5] Zou Y, Yao W, 2024, The Connotation, Dilemmas, and Path Choices for High-Quality Development of Vocational Education in the New Era. Journal of Heilongjiang Institute of Teacher Development, 43(02): 74–77.

[6] Wang Z, Zhang G, 2025, Research on the Collaborative Innovation Model of Science-Education Integration in Higher Vocational Education. Journal of Guizhou Open University, 33(02): 36–42.

[7] Yang J, 2022, Exploration of Practice-Oriented Curriculum Reform in Higher Vocational Education—Review of Research on Supply-Side Reform of Higher Vocational Education. China University Science & Technology, (11): 105.

[8] Chen L, 2024, Design of Problem Chain in Project-based Learning. Teaching and Management, (29): 21–24.

[9] Yi P, 2019, The Feasibility of Applying Problem-based Learning (PBL) in Higher Vocational Teaching. Science Consulting (Science and Technology Management), (13): 69–70.

[10] Liang X, Du J, Yu X, 2019, Cultivating College Students’ Research Capabilities Through Guided Education with Teachers’ Research Projects as the Carrier. Journal of Chengdu University of Traditional Chinese Medicine (Education Science Edition), 21(01): 31–33.